**Modern Physics Review**

**A. Know these Scientists and their contributions** (formula and dates are extra!)

|  |  |  |  |
| --- | --- | --- | --- |
| **Contribution** | **Formula** | **Name of Scientist** | **Date** |
| Mathematically Discovered electromagnetic waves, traveling at 3.0x108 m/s |  | Maxwell | 1865 |
| Used an interferometer to detect the luminiferous aether. Null result. |  | Michelson & Morley | 1887 |
| Light is sent in packets called photons | E = hf | Planck | 1900 |
| Studied Photelectric Effect in the Lab |  | Lenard | 1900 |
| Explained Photoelectric Effect | W = hf – Ek  (Work function) | Einstein | 1905 |
| Time dilation, Length contraction, Mass expansion | t = γto  L = Lo/γ  m = γmo | Einstein | 1905 |
| Mass-Energy Equivalence | E = mc2 | Einstein | 1905 |
| Planetary model of Atom |  | Rutherford | 1911 |
| Electron energy shells (orbitals) in atomic model |  | Bohr | 1913 |
| Electrons have spin |  | Stern-Gerlach | 1922 |
| Light has momentum | p = h/λ | Compton | 1923 |
| Particles of matter have wave properties | λ = h/mv | deBroglie | 1924 |
| Probability wave equation |  | Schrodinger | 1926 |
| Uncertainty principle | ΔxΔp > h  ΔtΔE > h | Heisenberg | 1927 |
| Muon Experiment (time dilation and length contraction) |  | Rossi-Hall | 1941 |

**B. True or False?**

|  |  |
| --- | --- |
| I am in a ship traveling at 0.9c. As a result, I notice the ship looks shorter | False – ship looks shorter to outside observer. Ship looks normal to observer in ship (at rest wrt ship). |
| An x-ray has a shorter wavelength than blue light. | True |
| Radio waves and X-rays travel at the same speed in a vacuum. | True |
| The faster a particle moves the greater the momentum of the particle | True |
| An electron can never be absolutely still for any length of time. | True |
| A photon has momentum | True |
| A photon has mass | False |
| A blue photon has more momentum than a red photon | True |
| The electron-volt is a unit of energy | True |

**C. Calculation Questions**

1. Convert 20eV to Joules. 20eV x 1.6x10-19J/eV = 32 x 10-19J
2. What is the definition of an electron volt? The potential energy lost/ kinetic energy gained when an electron moves across a potential of 1V
3. A photon has a frequency of 300 x 1012 Hz. What is the wavelength of this photon?

v = fλ λ = v/f = 3.0x108m/s ÷300x1012 = 1.0x10-7 m **Wavelength is 100nm (UV)**

1. A photon has an energy of 4.6eV. What is the wavelength of this photon? What “colour” is the photon? E = hf f = E/h = 4.6eV/4.14x10-15 eV∙s = 1.1x1015Hz

v = fλ λ = v/f = 3.0x108m/s ÷1.1x1015 = **2.7x10-7 m ultra violet**

Note: I used the other value of h, but you can also solve using h = 6.6x10-34 as long as you convert 4.6eV to Joules. You should get the same answer either way.

1. Silver has a work function of 4.52 eV. Find the maximum wavelength of a photon that will eject an electron from a plate of silver.

Ephoton = W + Ek electron -- in this case, we set Ek = 0

hf = 4.52 + 0 f = 4.52eV/4.14x10-15 eV∙s = 1.1x1015 Hz

v = fλ λ = v/f = 3.0x108m/s ÷1.1x1015 = 2.7x10-7m 270nm light

1. What happens if the photon in the previous question has a:
2. longer wavelength? The photon won’t be able to eject the electron
3. shorter wavelength? The photon will give the electron extra kinetic energy
4. UV Light with a wavelength of 3.00 x 102 nm is directed at a metallic surface. Electrons are ejected from the metal with a speed of 2.6 x 105m/s. Calculate the work function of the metal. Answer in eV.

photon:

λ = 3.00 x 102 nm = 300 x 10-9m = 3.00 x 10-7 m

E = hf = hc/ λ (get this from the wave eqn v = f λ and v for light is “c”)

Ephoton = 6.63x10-34 J∙s (3.00x108m/s) ÷ 3.00 x 10-7 m = 6.63x10-19 J

Electron:

Ek = ½ mv2 = ½ (9.11x10-31)(2.6x105)= 3.1x10-20 J

W = Ephoton – Ek = 6.6x10-19 – 3.1x10-20 = 6.32x10-19 J = 6.32/1.6 = 3.95eV

1. Put in order from greatest to least momentum:
2. Gamma ray photon of wavelength 2.4x10-12m.

p = h/ λ = 6.63x10-34/2.4x10-12 = 2.8x10-22 kg m/s (#2)

1. electron of mass 9.11x10-31kg moving at 5.0x106m/s.

p = mv = ( 9.11x10-31)(5.0x106) = 4.6x10-24 kg m/s (#3)

1. Elephant of mass 1200kg moving forward at 4.5m/s

p = mv = ( 1200)(4.5) = 5400 kg m/s (#1)

1. In the future, a rocket 30m long travels at a cruising speed of 0.5c. For a passenger on the rocket, the trip takes 20 minutes.
2. How long does the trip take according to Earth time?

t = γto = 1.15 (20) = 23.09 minutes (23 minutes and 5 seconds)

1. How long is the rocket according to observers on Earth as the rocket goes by?

L = Lo /γ = 30 / 1.15 = 26 m long

1. How far did the rocket travel?

We assume we want the distance as measured by a stationary observer

distance = v x t = 0.5 (3.0x108) x (23.09 x 60) = 2.1 x 1011 m (210 million km)

1. How far did the trip appear to the passengers?

d = v x t = 0.5 (3.0x108) x (20 x 60) = 1.8x1011 m (180 million km)

1. Summarize the trip as observed by passenger and observers on Earth.

To the passengers, the trip was shorter and took less time.

To the people on Earth, the trip took longer and went farther.

1. I boil 750ml of water by adding 3.0MJ of energy. How much does the mass of the water increase?

E = mc2

3.0x106 = m (3.0x108)2 so m = 1.0x10-10 kg

1. A substance has a half-life of 5.0s. A lab has a 800mg sample of the substance. How much will be left after exactly 1 minute?

N = No( ½ )n where n = 60/5.0 = 12

N = 800(0.5)12 = 0.195mg of the sample is left.

1. The sample in the previous question is raining down on us from the upper atmosphere at 0.9c.
2. According to someone on the earth’s surface, what is the half life of the substance?

t = γto = 2.29 (5.0) = 11.5s

1. How much is left after 1 minute?

N = 800 (.5)60/11.5 = 21.8mg left after 1 minute

1. An electron sits in the lowest shell of a hydrogen atom. The radius of the shell is 5.29x10-11 m. The electron is hit by a photon and jumps to the second shell, of radius 2.0x10-10m.
2. What is the electric potential of the first shell (include the sign)?

V = kQ/r = 9.0x109 (1.6x10-19) /5.29x10-11 = +27.2 Volts(close to the nucleus)

1. What is the electric potential of the second shell?

V = kQ/r = 9.0x109 (1.6x10-19) /2.0x10-10 = +7.2 Volts (farther from the nucleus)

1. What is the change in electric potential energy of the jump (include sign)? (this is a very simple calculation - don’t over do it!) Is the electric potential energy of the electron increased or decreased?

ΔE = qΔV = -1.6x10-19(7.2 – 27.2) = +3.2 x 10-18 Joules (gained pot. energy)

1. Where does this energy come from? It came from the photon that hit it.
2. What is the wavelength of the photon? What “colour” is this?

E = hc/ λ

λ = hc/E = 6.63x10-34 (3.0x108) / 3.2 x 10-18 = 6.2x10-8 m = 62 x 10-9m

62 nm is UV light (almost X-rays).

1. An electron and a positron (same particle with a positive charge) move toward each other at a slow speed. When they collide they annihilate and two gamma ray photons are emitted at 180o from each other.
2. Why are two photons needed? To conserve momentum (total momentum before is zero, total momentum after must be zero. Two photons must be emitted going in opposite directions)
3. Find the wavelength of the photons.

*There’s no information given! ... oh wait.*

Electron and positron annihilate – that means their mass is converted to energy. That energy is in the form of the 2 photons. For each particle, the energy is:

E = mc2

E = (9.11x10-31)(3.0x108)2 = 8.2x10-14 Joules of energy converted to a photon

E = hc/ λ

λ = 6.63x10-34 (3.00x108)/8.2x10-14 = 2.4x10-12 m

This is extremely small~~ 0.0024nm -- it is a gamma ray

1. An x-ray photon of wavelength 5.6nm strikes a stationary electron. The electron absorbs the photon and recoils at a velocity of 8.8x104 m/s [60oCCW from the original path of the x-ray]. The electron emits a secondary photon. Find:
2. the wavelength of the secondary photon.

This is a momentum question. If I put this on the test, there won’t be a lot of other questions!

e

60o

e

γ

γ

Horizontally (right +)

p = p’ Note: these should have vector

pγ + pe = pγ‘+ pe’ signs

h/λ + 0 = Pxγ + mv(cosθ)

6.63x10-34/5.6x10-9 = Pxγ+ 9.11x10-31(8.8x104)cos 60o

Pxγ = 1.18x10-25 – 4.01x10-26

= 7.8x10-26 kg m/s

Vertically (down +)

pγ + pe = pγ‘+ pe’

0 + 0 = Pyγ + mv(sinθ)

0 = Pyγ - 9.11x10-31(8.8x104)sin 60o

Pyγ = 9.11x10-31(8.8x104)sin 60o  = 6.94 x 10-26 kg m/s

Use Pythagoras to combine both Px and Py:

√(7.82 + 6.942) = 10.4 so p = 10.4 x 10 -26 kg m/s

Finally, p = h/λ so λ = 6.63x10-34 / 10.4 x 10-26 = 6.4 x 10-9 m

The secondary photon is only a little less energetic than the original photon. The electron does not take away much of the energy.

1. the angle of the secondary photon’s trajectory.

Tanθ = opp/hyp = Py/Px

Tanθ = 6.94/7.8

θ = tan -1(6.94/7.8)

θ = 42o

**D. Thinking Questions - answer in point form.**

*Note: Some of these answers are long and detailed. This is just to make sure you understand the underlying principles, not because I expect the same on a test.*

1. What is light, according to a) classical theory b) quantum theory.

Classical – light is an electromagnetic wave. It is created when an electron accelerates.

QM – light is made of photons – tiny light packets or particles. It is created when an electron loses potential energy.

1. How do you create:
2. radio waves b) microwaves c) visible light waves d) x-rays

radio – electrons accelerating up and down a long wire (>1 cm)

microwaves – same as radio, only short wire (<1cm) or when a molecule vibrates or twists

visible – electrons dropping from one shell to another (usually the 2nd shell)

x –rays – electrons dropping from top shell to innermost shell (big drop, big energy)

1. What is polarization and how can you demonstrate it with a radio?

Electrons vibrating in one dimension (up/down or left/right) create a linearly polarized E/M wave. Radio towers are vertical, creating a vertically polarized radio wave. Putting your radio antenna vertical will give best reception. Turning antenna sideways will give poor reception.

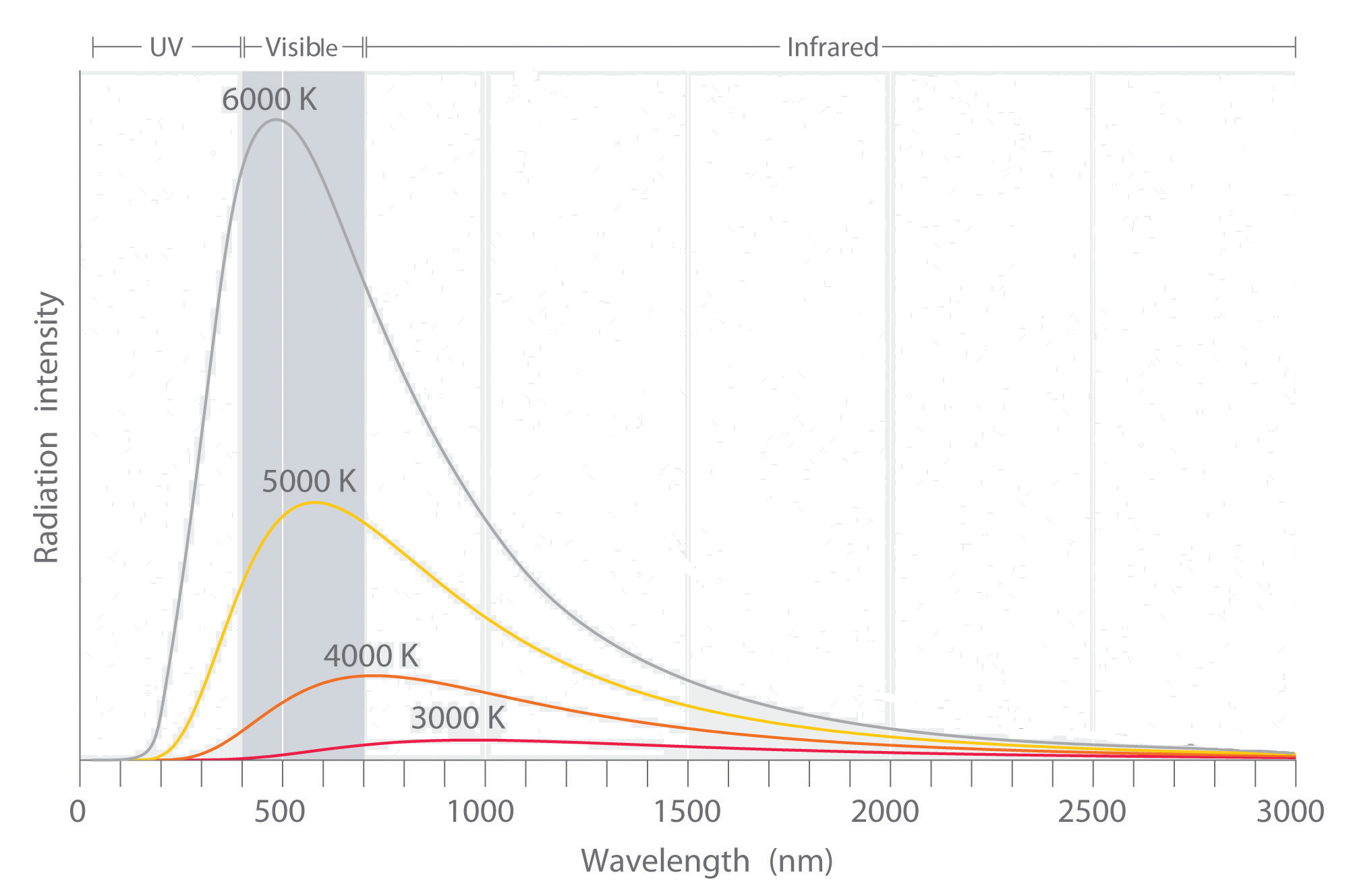
1. Explain why electrical appliances can emit red light (like a stove top) or white light (like a light bulb) but never green light.

Both use the fact that electrons running through a high resistance wire will heat up the wire. The many collisions going on in the wire cause atoms to bounce and electrons to jump shells randomly. Since the collisions are not carefully controlled, they will give a spread of energies to atoms and their electrons.

**Stove**: Low-energy collisions will produce low energy waves (Microwave, IR and some visible). The visible part will be just the red end of the spectrum. \

**Light Bulb**: Medium energy collisions produce medium energy waves (IR to Green). Since this covers most of the visible spectrum, we see this as white (a bit yellowish).

We could us the same principle (called incandescence) to create a bulb that would appear blue, but it would have to be high-energy, producing X-rays, UV and a little of the top end of the visible spectrum (violet and blue). We don’t because it would be too expensive due to energy consumption and lawsuits.



Stove

Fireball from a nuclear bomb

Incandescent Light Bulb

Incandescence will never produce a single colour in the middle of the visible spectrum because we can only produce a spread of wavelengths. To get a particular colour, we need to use other methods.

By the way, this is why there are a lot of red stars, blue stars and white stars (like our sun) but not many green stars.

1. Unlike a conventional light bulb, an LED is able to create a single pure colour (such as green). Why is this?

Because an LED is carefully designed to cause individual electrons to make a specific leap across a voltage gap. When the electrons leap, they lose a specific potential energy, producing a photon of the desired wavelength (and therefore colour).

1. Why does a 6V flashlight not produce X-rays?

A 6V battery gives 6Joules of energy to every Coulomb of charge. In other words, a 6V battery gives each electron 6eV of energy. Assuming all of this energy goes towards producing a photon, this corresponds to a wavelength of

λ = hc/E = 4.14x10-15 eV∙s (3.0x108) / 6eV = 2.1x10-7 m = 210 nm

This is in the UV range. This means that if a 6V flashlight was 100% efficient at turning the battery’s energy directly into light energy, it would still not be able to produce X rays. It’s impressive enough that you can produce UV light with a 6V battery.

1. I am wearing a red shirt.
2. Explain why it appears red.

White light from the sun/lights in the room hit the shirt. The blue/green/yellow etc photons (or waves) hit the shirt and are absorbed. The red photons (waves) are absorbed and then re-emitted (reflected).

1. What colour will the shirt appear if I shine green light on it? Explain.

Green light is absorbed by the shirt and not re-emitted (reflected). The t-shirt will appear black.

1. Use QM to explain why radiowaves will go through a plastic mesh but not a metal mesh.

A radio photon will hit the plastic mesh. The mesh has no electrons that are free to move very far. The energy of the photon cannot be absorbed, so it travels through the plastic. A metal mesh has free electrons (that’s why a metal conducts) so these electrons can absorb the photon and move up and down the mesh.

1. Bohr introduced his model of the atom to explain the spectral signature of the elements. Explain.

Before Bohr’s model, people couldn’t explain why the elements give off specific colours and no colour in between. Bohr introduced electron shells that act like steps. When an electron leaps down a shell, it gives off a photon. Each element has a different set of energy steps and so they give off their own characteristic colours.

1. Rutherford’s gold foil experiment showed that the atom had a massive positive nucleus and tiny negative electrons. He created the planetary model based on this description. He knew his model could not be right, but it was the best description he could come up with. What was wrong about his model?

He knew that Maxwell’s equations tell us that when an electron accelerates it gives off EM waves (light). Electrons orbiting a nucleus should be constantly emitting light as they accelerate around the nucleus. Also, as they do this, they should be losing energy, causing the electrons to plummet to the nucleus. Clearly this is not what is happening.

1. Heisenberg and Schrodinger helped create a better model of the atom. This model solves the problem with the Rutherford-Bohr model. Explain how.

In this model, the electrons aren’t moving around in a circle – they are sitting there in an “electron cloud”. Technically the electron isn’t moving at all, it is just occupying the entire space in the orbital.

1. What is radioactivity and how does quantum mechanics explain it?

Radioactivity is the act of atoms breaking apart. They do this because the protons in the nucleus repel each other. Some atoms are more unstable then others because they have too many protons and not the right amount of glue (neutrons) holding them together. We can predict which isotopes are stable and which are not. What we can’t predict is when an atom will break apart.

The randomness of radioactivity is typical of QM. According to QM, electrons are in a cloud around the nucleus. The electron has a highest probablity that it is where it is supposed to be – at its orbital radius from the centre, but there is a small probability that the electron is actually inside the nucleus. The electron may “quantum tunnel” its way into the nucleus, causing a nuclear reaction resulting in the atom becoming unstable (the electron combines with a proton creating a neutron). When an electron will do this is not possible to know, but the probability that it will happen in a certain time can be calculated.

Another way is to look at energy. A nucleus will stay together as long as nothing kicks it apart. Heisenberg says that during small time intervals, the energy of the nucleus varies (ΔEΔt=h). The smaller time interval we choose, the more the energy will vary. For brief moments then, the nucleus may (or may not) have enough energy to break apart. If we wait long enough, at some point, it will happen.

1. In the Rossi-Hall experiment, muons that have an extremely short half-life rain down on us from the upper atmosphere. Based on the short half-life, very few muons should make it to the base of the mountain. When the count is taken at the bottom of the mountain, the count is higher than expected. Use relativity to explain why this is:
2. from the point of view of the scientists on Earth

Muons are going close to speed of light. Their clocks appear to be running slow compared to ours. The half-life is longer than it would be on Earth. The muons live longer because they are living slower. Therefore more of them make it to the bottom of the mountain.

1. from the point of view of the muon.

Muons think that their half-life is the same as it always is. To them, we are the ones that are slow. However, the mountain looks shorter than it is. The time is normal, but the distance they travel is contracted, allowing them to make it to the bottom.

1. In the Stern-Gerlach experiment, electrons are found to have spin – as if they are spinning on their axis. This spinning makes the electrons magnetic. Explain why the S-G experiment was difficult to explain classically.

Classically if an electron has spin, then it is able to spin in any orientation. Also, if an electron is spinning in a certain direction (say with North pointing up) then I can perform the S-G experiment at various angles (up-down, 45o, horizontal) and expect different results from this electron. If I try a lot of electrons, I should get 360o worth of results.

The G-S experiment showed that the electron can only spin in two directions. Furthermore, the direction of the spin is fixed by the experiment. This makes sense in a quantum mechanical way, which is to say that it doesn’t make sense at all.